Chapter 2 - **THE NEUTRON PROBE**

1. WHAT ARE NEUTRONS?

The neutron was discovered by Chadwick in 1932. It has zero charge, a mass of 1.0087 atomic mass unit, a spin of 1/2 and a magnetic moment of -1.9132 nuclear magnetons. It has a lifetime of 894 seconds and decays into a proton, an electron and an antineutrino. Its interactions with matter are confined to the short-range nuclear and magnetic interactions. Since its interaction probability is small, the neutron usually penetrates well through matter making it a unique probe for investigating bulk condensed matter. Since the neutron can be reflected by some surfaces when incident at glancing angles, it can also be used as a surface probe. Neutrons are scattered by nuclei in samples or by the magnetic moments associated with unpaired electron spins (dipoles) in magnetic samples. The nuclear scattering potential is short range so that most neutron scattering can be described by "s wave" scattering (zero orbital angular momentum) and the scattering cross section can be described by the first Born approximation. Higher order term in the Born expansion series are required for neutron reflection from surfaces. Reflection involves the refraction (not diffraction) limit.

Some useful properties follow:

Mass: $m = 1.675*10^{-24}$ gm
Magnetic Moment: $\mu_n = 6.031*10^{-12}$ eV/gauss
Energy: $E[\text{meV}] = \dfrac{81.787}{\lambda^2[\text{Å}^2]}$
Wavelength: λ [Å] = 3955/v [m/sec]
Velocity: v = 1 m/msec (at λ=4 Å)
Useful relationship: $mv\lambda = h$.

Thermal neutrons correspond to 25 meV energies and 1.8 Å wavelength.

2. WHY USE NEUTRONS?

Neutrons are both a bulk and a surface probe for investigating both structures and dynamics. Some of the advantages of neutrons as a probe for condensed matter follow.

-- Neutrons interact through short-range nuclear interactions. They are very penetrating and do not heat up (i.e., destroy) samples. Neutrons are good probes for investigating structures in condensed matter.

-- Neutron wavelengths are comparable to atomic sizes and inter-distance spacing. Neutron energies are comparable to normal mode energies in materials (for example phonons, diffusive modes). Neutrons are good probes to investigate the dynamics of solid state and liquid materials.

-- Neutrons interactions with hydrogen and deuterium are widely different making the deuterium labeling method an advantage.

Someone once stated that “neutrons never lie!”. Trust what they’re telling you.

QUESTIONS

1. The neutron decays into what particles? How about the proton? Does it decay?
2. Why are neutrons a good probe to investigate condensed matter?
3. Can neutrons get reflected from surfaces at large angles like light does?
4. Define the electronvolt (eV) in terms of the SI energy unit, the joule (J).

ANSWERS

1. The neutron decays into an electron, a proton and an anti-neutrino. The proton is stable. Its decay has not been observed.
2. Neutrons are a good probe to investigate condensed matter because it is very penetrating (due to its charge neutrality) and to its just-right typical wavelengths and kinetic energies.
3. Neutrons can be reflected from surfaces only at low glancing angles. They cannot be reflected at large angles from surfaces.
4. The electrostatic energy is the product of the charge by the applied voltage. The electronvolt is the energy of 1 electron in a potential of 1 volt. The charge of 1 electron is $1.602*10^{-19}$ coulomb. Therefore, $1eV = 1.602*10^{-19}$ J.